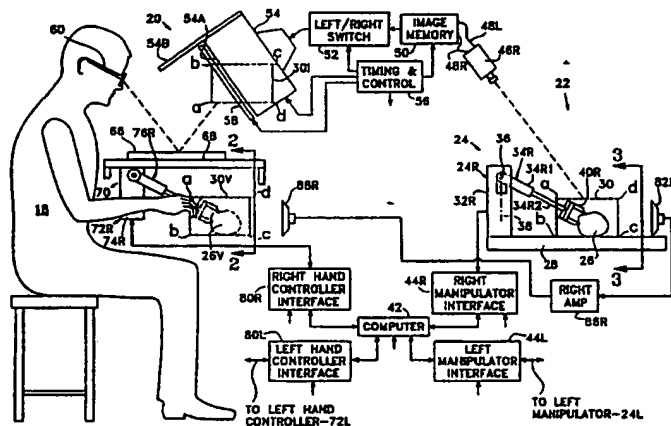




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(54) Title: TELEOPERATOR SYSTEM AND METHOD WITH TELEPRESENCE



(57) Abstract

A teleoperator system with telepresence is shown which includes right and left hand controllers (72R and 72L) for control of right and left manipulators (24R and 24L) through use of a servomechanism that includes computer (42). Cameras (46R and 46L) view workspace (30) from different angles for production of stereoscopic signal outputs at lines (48R and 48L). In response to the camera outputs a 3-dimensional top-to-bottom inverted image (30I) is produced which, is reflected by mirror (66) toward the eyes of operator (18). A virtual image (30V) is produced adjacent control arms (76R and 76L) which is viewed by operator (18) looking in the direction of the control arms. By locating the workspace image (30V) adjacent the control arms (76R and 76L) the operator is provided with a sense that end effectors (40R and 40L) carried by manipulator arms (34R and 34L) and control arms (76R and 76L) are substantially integral. This sense of connection between the control arms (76R and 76L) and end effectors (40R and 40L) provide the operator with the sensation of directly controlling the end effectors by hand. By locating visual display (246) adjacent control arms (244R and 244L) image (240I) of the workspace is directly viewable by the operator (Figs. 12 and 13). Use of the teleoperator system for surgical procedures is also disclosed (Figs. 7-9 and 13).

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TELEOPERATOR SYSTEM AND METHOD WITH TELEPRESENCE

FIELD OF THE INVENTION

This invention relates generally to teleoperator method and apparatus, and particularly to those which include means for providing the operator of remote apparatus with the same sense as working directly with his hands at the worksite.

BACKGROUND OF THE INVENTION

Teleoperating, which is well known, includes the human performance of tasks at a remote location using manipulators. Telepresence includes providing the teleoperator with the same feedback and control that he would have were he actually at the worksite carrying out the operation with his own hands. Telepresence operation generally includes use of a stationary visual display, particularly a stereographic visual display of the remote workspace. Stereoscopic television systems are well known as shown, for example, in U.S. Patent Numbers 4,562,463 and 4,583,117 and in U.K. Patent Application GB 2,040,134.

Remote manipulators employing stereoscopic TV viewing together with force feedback also are well known as shown, for example, in an article entitled, "Controlling Remote Manipulators Through Kinesthetic Coupling," Bejczy et al, Computers in Mechanical Engineering, July 1983, pps. 48-60, and in an article entitled, "Stereo Advantage for a Peg-In-Hole Task Using a Force-Feedback Manipulator" by E.H. Spain, SPIE Vol. 1256 Stereoscopic Displays and Applications, 1990, pps.

244-254. In the Bejczy et al article, force-torque feedback is disclosed. Also, in U.S. Patent Number 3,921,445, a manipulator which includes force, torque and slip sensors of a type which may be employed with the present invention is shown.

Even though the operator of prior art manipulators is provided with a stationary three-dimensional image of the workspace, and manual controllers for control of the manipulators are provided with feedback, the operator is not provided with a sense of actually being present at the worksite. The present invention is directed to a viewing arrangement for use in a remote manipulation system which substantially adds to the operator's sense of presence at the remote manipulator site.

15 SUMMARY AND OBJECTS OF THE INVENTION

An object of this invention is the provision of an improved teleoperator system and method which include an improved viewing system to enhance the operator's sense of presence at remote manipulators controlled by the operator from a remote location.

An object of this invention is the provision of an improved teleoperator system and method of the above-mentioned type wherein an image of manipulator end effectors for viewing by the operator are sensed by the operator as comprising an integral part of hand-controllers used by the operator to control the end effectors, thereby giving the operator a strong sense of presence at the worksite.

An object of this invention is the provision of an improved teleoperator system and method of the above-mentioned type which is well adapted for use in a wide variety of applications including military, industrial, biomedical, and the like.

The present invention includes manipulators located at a worksite and which are controlled by hand-operated

means at a remote operator control station. End effectors at the manipulators are used for manipulating objects located in a workspace at the worksite, and force-torque feedback is employed for transmitting back to the operator mechanical resistance encountered by the end effectors. Stereographic visual display means provide the operator with an image of the workspace. In accordance with the present invention, the image is located adjacent the hand-operated means so that the operator looks in the direction of the hand-operated means for viewing the image adjacent the hand-operated means. Either a real or virtual image of the workspace may be provided adjacent the hand-operated means. Display means for display of a real image may be located adjacent the hand-operated means for direct viewing of the real image by the operator. For display of a virtual image of the workspace, a mirror is located between the operator's eyes and the hand-operated means. In this case, display means provide a real image which is inverted from top to bottom, which inverted image is viewed via the mirror, which mirror inverts the image and provides the operator with a virtual image of the workspace, which appears to be located adjacent the hand-operated means. By locating the image of the workspace adjacent the hand-operated means the operator is provided with a sense that the end effectors and hand-operated means are substantially integral despite the fact the end effectors are located at the worksite and the hand-operated means are located at the remote operator's station. A stereophonic sound system may be included to provide the operator with stereophonic sound from the worksite. Video camera means are provided for viewing the workspace from which an image of the workspace is obtained. Various other sensors and associated responders may be located at the worksite and operator's

station, respectively, for transmission of pressure, tactile, heat, vibration and similar information for enhanced telepresence operation.

Depending upon the application, different scaling
5 may be provided in the transmission of information between the operator's station and worksite. For example, for microassembly, microsurgery and like operations involving small part manipulation, optical and/or video magnification may be employed to provide an
10 enlarged 3-dimensional image for viewing by the operator. With similar scaling between the hand operated means and manipulators, the perception of the operator is substantially that which a miniature operator would have were he at the worksite.

15 BRIEF DESCRIPTION OF THE DRAWINGS

The invention, together with other objects and advantages thereof, will be better understood from the following description considered with the accompanying drawings. It will be understood that the drawings are
20 for purposes of illustration and example only, and that the invention is not limited thereto. In the drawings, wherein like reference characters refer to the same parts in the several views,

Fig. 1 is a diagrammatic showing of a teleoperator
25 system embodying the present invention including side elevational views of a worksite and remote control operator's station;

Fig. 2 is an enlarged rear elevational view of the operator's station taken substantially along line 2-2 of
30 Figure 1;

Fig. 3 is an enlarged rear elevational view of the worksite taken substantially along line 3-3 of Figure 1;

Fig. 4 is a simplified side elevational view which is similar to Figure 1 and showing dimensional
35 relationships between elements at the worksite and

elements at the operator's station;

Fig. 5 is a diagrammatic view to illustrate visual perception by a miniature virtual eye, and Fig. 6 is a diagrammatic view to illustrate visual perception by the operator when image magnification is employed;

Fig. 7 is a diagrammatic view which is similar to that of Fig. 1 but showing the teleoperator system used for telepresence surgery;

Fig. 8 is a rear elevational view of the operator's station shown in Fig. 7;

Fig. 9 is a rear elevational view of the worksite shown in Fig. 7;

Figs. 10 and 11 are fragmentary side elevational views of modified forms of operator's station and manipulator, respectively, having increased degrees of freedom;

Fig. 12 is a side elevational view of a modified form of operator's station wherein display means are positioned for direct viewing by the operator;

Fig. 13 is a rear elevational view of the modified form of operator's station shown in Fig. 12; and

Fig. 14 shows a fragmentary portion of the insertion portion of an endoscope for use with the present invention.

Reference now is made to Figs. 1-3 wherein the teleoperator system is shown to include an operator's station 20 (Figs. 1 and 2) and worksite, 22 (Figs. 1 and 3). An operator 18 at the operator's station controls manipulator means 24 at the remote worksite. Manipulator means 24, comprising right and left manipulators 24R and 24L, respectively, are used for manipulating objects, such as object 26 which is shown located on a platform, or base, 28 within a workspace 30 shown in broken lines. For purposes of illustration only, and not by way of limitation, the right manipulator 24R is shown to

comprise a housing 32R affixed to base 28 and from which housing a telescopic arm 34R extends. The inner end 34R1 of arm 34R is mounted for pivotal movement in any pivotal direction using conventional mounting means. For example, the inner end of arm 34R may be mounted for pivotal movement about a horizontal pivot axis 36 which pivot axis, in turn, is adapted for pivotal movement about vertical axis 38.

Arm 34R includes telescopic inner section 34R1 and outer section 34R2, which outer section is adapted both for axial movement into and out of inner section 34R1 and for rotation about its longitudinal axis. An end effector 40R is carried at the outer end of the arm which, for purposes of illustration, is shown to comprise a gripper. Motor means, not shown, control pivotal movement of arm 34R about pivot axes 36 and 38, axial and rotary movement of outer arm section 34R2 along and about the longitudinal axis of the arm, and opening and closing of gripper 40R. The motor means, together with motor control circuits for control of the motors, may be included in housing 32R. The motors are under control of a computer 42 connected thereto through right manipulator interface 44R and the above-mentioned motor control circuits.

The left manipulator 24L is of substantially the same design as the right manipulator 24R and the same reference numerals, but with the suffix L instead of R, are used to identify similar parts. For purposes of illustration, the left end effector 40L, shown in Fig. 3, is seen to comprise cutting blades which operate to cut in the manner of a pair of scissor blades.

The worksite is provided with a pair of video cameras 46R and 46L for viewing workspace 30 from different angles for production of stereoscopic signal outputs therefrom at lines 48R and 48L. The angle γ

between the optical axes of the cameras shown in Fig. 3 is substantially equal to the operator's interocular viewing angle γ of an image of the workspace as shown in Fig. 2.

5 The video camera outputs at lines 48R and 48L are supplied to an image memory 50 for momentary storage of video fields of right and left images from the cameras. Fields of right and left images from image memory 50 are alternately supplied through left/right switch means 52
10 to visual display means 54, such as a television monitor, for alternate display of the two images at the face 54A of the monitor. Timing and control means 56 provide timing and control signals to various elements of the system, including elements included in the stereographic
15 display system, for signal timing and control of the system. If digital storage means 50 are employed, then conversion of the camera signal outputs to digital signal form by analog to digital converter means prior to storage, and conversion of the digital signal output from
20 left/right switch means to analog signal form in preparation for display at monitor 54 may be employed.

 An electrooptical device 58 at the face of the display means 54 controls polarization of light received from display means 54 under control of a left/right
25 synchronizing signal from timing and control unit 56. The left and right image fields are viewed by operator 18 wearing a pair of passive polarized glasses 60 having right and left polarizing elements 62 and 64 polarized in orthogonal directions. The polarization of light from
30 display 54 through electrooptical device 58 is synchronized field by field such that the right field is occluded from the left eye and the left field is occluded from the right eye for stereographic viewing by the operator. Other means for stereographic viewing of left
35 and right image fields are well known, including, for

example, those using active stereographic glasses, which may be used in the practice of this invention to provide the operator with a stereoscopic view of the remote workspace.

5 The vertical deflection coil connections for monitor 54 are reversed, causing the monitor to scan from bottom to top thereby creating a top-to-bottom inverted image 30I of workspace 30. Letters a, b, c and d are used to identify corresponding corners of the workspace 30 and
10 inverted workspace image 30I. The inverted workspace image 30I is viewed by the operator via a mirror 66 at the top of a table 68, which mirror inverts image 30I to return the image as viewed by the operator to an upright position. Looking downwardly in the direction of the
15 mirror, the operator views a virtual image 30V of workspace 30. In accordance with one aspect of the present invention, the image viewed by the operator, which in the Fig. 1-3 embodiment comprises a virtual image, is located adjacent controller means 70 used by
20 the operator for control of manipulator means 24 at the worksite.

 Controller means 70 are shown located beneath the table top 68 and include right and left controllers 72R and 72L for control of the respective right and left
25 manipulators 24R and 24L. The right and left controllers are of substantially the same design so that a description of one applies to both. As with the manipulators, the suffixes R and L are used to distinguish elements of the right controller from those
30 of the left controller. For purposes of illustration, and not by way of limitation, the right controller 72R is shown to comprise a housing 74R affixed to the bottom of table top 68 and from which hand-operated means 76R in the form of a telescopic control arm, or stick, extends.

35 The right and left control arms 76R and 76L are

provided with the same degrees of freedom as the associated manipulator arms 34R and 34L, respectively. For example, the inner end of control arm 76R is mounted for pivotal movement about a horizontal pivot axis, corresponding to manipulator pivot axis 36, which axis, in turn, is adapted for pivotal movement about an intersecting vertical axis, corresponding to manipulator axis 38. Control arm 76R also includes inner section 76R1 and outer section 76R2, which outer section is adapted both for axial movement into and out of inner section 76R1 and for rotation about its longitudinal axis. It will be apparent that the control arm 76R is provided with the same four degrees of freedom as the associated manipulator arm 34R. Additionally, sensor means 78R are located adjacent the outer end of outer arm section 76R2 for use in controlling gripping action of gripper 40R. Similar sensor means 78L adjacent the outer end of control arm 76L are adapted for use in controlling operation of scissor blades 40L.

Right and left controllers 72R and 72L are included in a servomechanism system wherein mechanical motion of control arms 76R and 76L controls the position of manipulator arms 34R and 34L, and pressure on sensor means 78R and 78L controls opening and closing of end effectors 40R and 40L, respectively. In Fig. 1, right and left hand controller interfaces 80R and 80L, respectively, are shown for connection of the controllers to computer 42. Servomechanisms for control of mechanical motion at a remote location are well known, including those which provide force and torque feedback from the manipulator to the hand-operated controller means. Any suitable prior art servomechanism may be used in the practice of the present invention, with those incorporating force and torque feedback being particularly preferred for telepresence operation of the

system. In the illustrated system, right and left microphones are included at the worksite, outputs from which microphones are amplified by right and left amplifiers and supplied to right and left speakers at the operators' station for providing a stereophonic sound output to provide the operator with an audio perspective present at the workspace. In Fig. 1, only the right channel of the stereophonic system is shown including right microphone 82R, right amplifier 86R and right speaker 88R. The left microphone and speaker are located directly behind the respective right microphone and speaker at the worksite and operator's control station as viewed in Fig. 1. Obviously, earphones may be provided for use by the operator in place of the speakers which would help to block out external noises at the operator's control station. Also, in Fig. 1 a light shield 54B at the monitor is shown for blocking direct viewing of the monitor face by the operator.

Reference now is made to Fig. 4 wherein a simplified diagrammatic view of the system illustrated in Figs. 1-3 is shown and wherein various lengths and angular positions are identified by reference characters. In Fig. 4, the optical path length between the cameras and a point F at the workspace is identified by reference character L. A corresponding path length between the operator's eyes and point F at the virtual image of the workspace is identified by the distance $a+b$, where a is the distance from the eyes of the operator to mirror 66, and b is the distance from the mirror to point F at the virtual image. Other dimensions shown include the height G of the cameras above the pivot point of manipulator arm 34R and corresponding height g of the operator's eyes above the pivot point of control arm 76R. With the control arm 76R at length d , the manipulator arm 34R adjusts to length D. Similarly, with the control arm 76R

at an angle β_A with the vertical, the manipulator arm 34R is positioned at the same angle from vertical. The angle from vertical at which the cameras view the workspace and the eyes view the virtual image of the workspace is identified by α .

Between elements of the worksite and operator station, the following relationships pertain:

$$a + b = kL, \quad (1)$$

$$d = kD, \quad \text{and} \quad (2)$$

$$g = kG \quad (3)$$

where k is a scale factor constant.

When k equals 1 such that $a + b = L$, $d = D$ and $g = G$, no scaling of worksite dimensions is required.

Any scale factor may be employed, the invention not being limited to full-scale manipulation. For example, the worksite can be small, including microscopic in size, in which case the optical parameters, including distance to object, interocular distance and focal length, and mechanical and dimensional parameters are appropriately scaled.

By using appropriate scaling and image magnification and force and torque feedback, and by locating the image 30V of the workspace 30 adjacent hand-operated control means 76R and 76L, the operator is provided with a strong sense of directly controlling the end effectors 40R and 40L. The operator is provided with a sense that the end effectors 40R and 40L and respective control arms 76R and 76L are substantially integral. This same sense of togetherness of the hand-operated control means and end effectors is not provided in prior art arrangements wherein the image viewed by the operator is not located adjacent the hand-operated control means. Even where the prior art includes stereoscopic viewing and force and torque feedback, there is a feeling of disconnectedness of the hand motions from the visual image object being

worked upon. The present invention overcomes this sense of disconnectedness by locating the workspace image where the operator's hands appear to exercise direct control over the end effectors.

5 For small-scale manipulation, such as required for surgical applications, it is desired to replicate the visual experience that a miniature observer would have were he closely adjacent the actual worksite. In Fig. 5, the virtual eye 90 of a hypothetical miniature observer is shown viewing an actual workspace. Light from a source at a point X, Y, Z in the actual workspace produces a stimulus on the miniature observer's eye 90 at a point identified as X'/M. In Fig. 6, an eye 92 of an actual operator is shown viewing an enlarged image of the virtual workspace produced by means of a video camera 94 used to view the actual workspace. The illustrated camera includes a light-receiving lens 96 and solid state imaging device such as a charge-coupled-device (CCD) array 98 where the point light source at X, Y, Z is shown
10 imaged at point X_i , Y_i , Z_i . With correct scaling, a corresponding light source is produced at point MX_i , MY_i , MZ_i at either the real or apparent position of the face of the visual display which, due to stereoscopic operation of the system appears to the operator to
15 originate from point MX, MY, MZ corresponding to point X,Y,Z at the actual workspace. At the retina of the actual eye 92, a stimulus is produced, at point X' at proportionately the same position as point X'/M at eye 90 of the hypothetical observer. This relationship is
20 ensured by selecting a correctly scaled camera distance and lens focal length such that the optical magnification $M_o = M/M_v$ where M is the desired overall magnification and M_v is the video magnification. A typical video magnification, M_v , which equals the ratio of the CCD-array 98 width to the display width, is about 40.
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Reference now is made to Figs. 7 through 9 wherein a modified form of this invention is shown for medical use. Here, right and left manipulators 100R and 100L are shown which are under control of right and left
5 controllers 102R and 102L, respectively. Elements of the imaging system are substantially the same as those employed in the imaging system illustrated in Figs. 1-3 described above except that an enlarged virtual image 104V of actual workspace 104 is provided for viewing by
10 the operator. Also, servomechanism elements for connection of the right and left controllers 102R and 102L to the respective manipulators 100R and 100L are substantially the same as those described above with reference to Figs. 1-3. In the illustrated arrangement,
15 the right and left manipulators are of substantially the same construction as are the right and left controllers, such that a description of one manipulator and one controller applies to both. Again, suffixes R and L are used to distinguish between right and left elements
20 thereof.

The manipulators include outer control sections 100RA and 100LA and insertion sections 100RB and 100LB, which insertion sections are adapted for insertion into a body cavity through cylindrical tubes, or cannulas, not
25 shown. For purposes of illustration, the manipulators are shown inserted through the abdomen wall 106 of a subject. As is well understood, for laparoscopic surgical procedures, wall 106 is separated from internal organs by insufflation wherein a gas is introduced into
30 the abdomen by any suitable means not shown. Manipulator motors and associated motor control circuits are contained in the outer control sections 100RA and 100LA of the manipulators for control of the insertion section. The manipulators, together with a laparoscope 108 for
35 viewing organs within the cavity, are carried by a fixed

rail 110 forming part of a surgical table upon which the subject is supported.

The insertion sections 100RB and 100LB of the manipulators may be of substantially the same design as
5 manipulator arms 34R and 34L described above with reference to the Figs. 1-3 embodiment. The insertion sections are of relatively small size for use inside the body. Insertion section 100RB includes telescopic inner section 112R1 and outer section 112R2, which outer
10 section is adapted for both axial movement into and out of inner section 112R1 and for rotation about its longitudinal axis. End effectors 114R and 114L are carried at the outer ends of the respective right and left sections 112R2 and 112L2 for manipulation of organ
15 116. The inner section 112R1 is adapted for pivotal movement about intersecting perpendicular axes located substantially at point P where the insertion section intersects wall 106. Exclusive of operation of end effectors 114R and 114L the manipulator arms each are
20 provided with four degrees of freedom, the same as in the embodiment shown in Figs 1-3. End effectors 114R and 114L simply may comprise, essentially, microsurgical instruments with their handles removed including, for example, retractors, electrosurgical cutters and
25 coagulators, microforceps, microneedle holders, dissecting scissors, blades, irrigators, and sutures.

Laparoscope 108 for viewing the workspace 104 is shown comprising an outer operating section 108A and insertion section 108B. The outer end section 120 of
30 insertion section 108B is axially and rotatably movable within the inner end 122 thereof, and is provided with a pair of image transmission windows 124,124 for stereoscopic viewing of workspace 104. The laparoscope also is provided with illuminating means, not shown for
35 illuminating the workspace, and with liquid inlet and

outlet means, not shown, for flow of liquid past the windows. Video camera means within section 108A are responsive to light received through the viewing windows for generation of left and right electronic images at output lines 48R and 48L for connection to image memory 50. A magnified 3-dimensional image 104I is produced at display means 54 for viewing by the operator wearing cross-polarized glasses 60 via mirror 66. As with the embodiment shown in Figs. 1-3, a virtual image 104V of the workspace 104 is produced adjacent control arms 130R and 130L of controllers 102R and 102L. Control arms 130R and 130L are of the same type as control arms 76R and 76L included in the Figs. 1-3 embodiment described above. They include telescopic inner and outer sections 132R1 and 132R, and 132L1 and 132L2. Sensor means 134R and 134L located adjacent the outer ends of the control arms control operation of end effectors 114R and 114L, respectively, in the manner described above with reference to Figs. 1-3. It here will be noted that the angle from vertical at which the image is viewed by the operator need not equal the angle from vertical at which the object is viewed by the cameras. In the arrangement illustrated in Figs. 7-9, the operator is shown to view the image 104V at an angle θ from vertical (Fig. 7) whereas the object 116 is shown as viewed directly downwardly. With no external reference, the sense of vertical within a body is not particularly great, and no confusion is produced in the mind of the operator as a result of the different observer and camera viewing angles relative to vertical.

With the Figs. 7-9 embodiment, not only is a magnified virtual image 104V of the workspace provided for viewing by the operator, but control arms 130R and 130L of greater length than the length of the manipulator

insertion sections 100RB and 100LB are employed. Servomechanism scaling of axial movement of the telescopic control arms is provided such that axial extension or retraction thereof results in a smaller
5 extension or retraction of the telescopic insertion sections. Angular pivotal motion of the control arms 130R and 130L produces the same angular pivotal motion of insertion sections 100RB and 100LB, and rotational
10 movement of the end sections 132R2 and 132L2 of the control arms produces the same rotational motion of end sections 112R2 and 112L2 of the insertion sections of the right and left manipulators, without scaling. This
embodiment of the invention, with its magnified image, is of particular use in the area of microsurgery, and
15 especially in those cases where the surgeon cannot reach an area by hand because of size constraints.

The present invention is not limited to use with manipulators having any particular number of degrees of freedom. Manipulators with different degrees of freedom
20 which are well known in the art may be used in the practice of this invention. In Figs. 10 and 11, to which reference now is made a controller 140 and manipulator 142, respectively, are shown which include a wrist joint to provide the same with additional freedom of movement.
25 The illustrated controller 140 includes a housing 144 affixed to the bottom of table top 68 upon which table mirror 66 is located. An enlarged virtual image 146V of actual workspace 146 is provided adjacent the operator's hand 148 viewable by the operator when looking downwardly
30 onto the mirror 66 in a manner described above.

A control arm 150L comprising inner and outer sections 150L1 and 150L2, respectively, is mounted within housing 144 for pivotal movement in any pivotal direction as indicated by intersecting double-headed arrows 152 and
35 154. The outer section 150L2 is adapted for axial

movement into and out of inner section 150L1 in the direction of double-headed arrow 156. It also is adapted for rotation about its longitudinal axis in the direction of double-headed arrow 158. In this embodiment, the control arm includes an end section 160 pivotally attached to outer section 150L2 by wrist joint 162 for pivotal movement in the direction of double-headed arrow 164. End section 160 comprises axially aligned inner and outer sections 160A and 160B, the outer section 160B of which is rotatable about its longitudinal axis in the direction of double-headed arrow 166. As with the above-described arrangements, sensor means 168 are located adjacent the free end of the control arm for operation of an end effector 170 at manipulator 142 shown in Fig. 11.

Referring to Fig. 11, end effector 170 is shown to comprise a pair of movable jaws attached to a wrist 172 comprising axially aligned links 172A and 172B. Outer link 172B is rotatable about its longitudinal axis relative to inner link 172A by motor means, not shown, in the direction of double-headed arrow 166M in response to rotation of section 160B of the hand-operated control unit in the direction of arrow 166. Wrist link 172A is pivotally attached to manipulator forearm 174 for pivotal movement in the direction of double-headed arrow 164M in response to pivotal movement of end section 160 of the hand-operated control means about pivot axis 162. Forearm 174 is longitudinally axially movable in the direction of double-headed arrow 156M in response to axial movement of outer section 150L2 of control arm 150L in the direction of double-headed arrow 156. It also is rotatable about its longitudinal axis in the direction of double-headed arrow 158M in response to rotation of outer section 150L2 of control arm 150L in the direction of double-headed arrow 158. Additionally, it is pivotally movable about point 176 in the directions of double-

headed arrows 152M and 154M in response to pivotal movement of control arm 150L in the directions of double-headed arrows 152 and 154, respectively. For biomedical use, such as remote laparoscopic surgery, pivot point 176
5 is substantially located at the level of abdominal wall 178 through which the manipulator extends. In Fig. 11, manipulator arm 174 is shown extending through a cannula 180 which penetrates the abdominal wall.

The outer operating end of the manipulator is
10 adapted for attachment to a supporting rail, not shown, of the surgery table upon which the subject is supported. It includes an end effector drive motor 182 for opening and closing of gripper 170. Wrist drive motor 184 controls pivotal movement of wrist 172 in the direction
15 of double-headed arrow 164M, and extension drive motor 186 controls axial movement of manipulator arm 174 in the direction of double-headed arrow 156M. Forearm pivotal control motors and linkages, identified generally by reference numeral 188, provide for pivotal movement of
20 arm 174 about pivot point 176 in the directions of arrows 152M and 154M. Pivotal motion about point 176 is provided by simultaneous lateral movement of the outer operating end of the manipulator and pivotal movement of arm 174. Movements are coordinated such that the center
25 of rotation of forearm 174 is fixed in space at point 176 at the level of the abdominal wall.

Controller 140 and manipulator 142, are included in a system such as shown in Figs. 7, 8 and 9 which includes a second controller and manipulator for use by the
30 operator's right hand, and associated servomechanism means of any suitable type, not shown, for remote control of the manipulators by the hand-operated controllers. Video camera means at the worksite, such as shown in Fig. 9, together with display means, such as shown in Fig. 7,
35 are employed for providing the operator with an image of

the workspace at a location adjacent the left and right hand-operated control means. By using manipulators with a wrist joint, an added degree of freedom is provided for increased maneuverability and usefulness thereof.

5 However, as noted above, the present invention is not limited to use with manipulators with any particular degree of freedom.

Reference now is made to Figs. 12 and 13 wherein a modified form of this invention is shown which provides
10 for direct viewing of a 3-dimensional image 240I of a workspace, not shown. In Figs. 12 and 13, only the operator's station is shown, which includes right and left controllers 242R and 242L and associated right and left hand-operated means 244R and 244L which may be of
15 the same type as controllers and control arms described above. The operator's station is adapted for remote control of manipulators which also may be of the above-described type. The 3-dimensional image 240I of the workspace is provided by visual display means 246 in
20 conjunction with electrooptical device 58 at the face of the display means and cross-polarized glasses 60 worn by the operator, to which display means left and right video fields from left and right video cameras that view the workspace are alternately supplied, all in the manner
25 described in detail above. End effector and object images 248 and 250, respectively, are shown within the workspace image as viewed by video cameras at the worksite. The display means 246 is located adjacent the left and right hand-operated means 244R and 244L for
30 direct viewing by the operator. With this arrangement, the end effector and object images together with the hand-operated means 244R and 244L are simultaneously viewable by the operator. Since the hand-operated means also are visible, the operator is provided with a visual
35 sense of connection between the end effector means and

hand-operated means whereby they appear substantially as being integral.

Reference now is made to Fig. 14 wherein the distal end portion, or tip, 260 of the insertion section of an endoscope is shown which is of substantially the same type as shown in the above-mentioned publication entitled "Introduction to a New Project for National Research and Development Program (Large-Scale Project) in FY 1991" which endoscope may be used in the practice of the present invention. The insertion end of the endoscope includes a pair of spaced viewing windows 262R and 262L and an illumination source 264 for viewing and illuminating a workspace to be observed. Light received at the windows is focused by objective lens means, not shown, and transmitted through fiber-optic bundles to a pair of cameras at the operating end of the endoscope, not shown. The camera outputs are converted to a 3-dimensional image of the workspace which image is located adjacent hand-operated means at the operator's station, not shown. Right and left steerable catheters 268R and 268L pass through accessory channels in the endoscope body, which catheters are adapted for extension from the distal end portion, as illustrated. End effectors 270R and 270L are provided at the ends of the catheters which may comprise conventional endoscopic instruments. Force sensors, not shown, also are inserted through the endoscope channels. Steerable catheters which include control wires for controlling bending of the catheters and operation of an end effector suitable for use with this invention are well known. Control motors for operation of the control wires are provided at the operating end of the endoscope, which motors are included in a servomechanism of a type described above for operation of the steerable catheters and associated end effectors from a remote operator's station. As with the

other embodiments, the interfacing computer in the servomechanism system remaps the operator's hand motion into the coordinate system of the end effectors, and images of the end effectors are viewable adjacent the hand-operated controllers in a manner described above. With this embodiment, the operator has the sensation of reaching through the endoscope to put his hands directly on the end effectors for control thereof. Endoscopes of different types may be employed in this embodiment of the invention so long as they include one or more accessory channels for use in control of end effector means, and suitable viewing means for use in providing a visual display of the workspace. For example, gastric, colonscopic, and like type endoscopes may be employed.

The invention having been described in detail in accordance with requirements of the Patent Statutes, various other changes and modifications will suggest themselves to those skilled in this art. For example, as noted above, the invention may include the use of tactile feedback to provide the subtle sensations for palpation and for manipulating tissues and instruments. To provide this feedback, tactile sensor arrays may be included on the end effectors which are coupled to tactile sensor stimulator arrays on the hand-operated control means, which reproduce the tactile sensation on the operator's hands. A variety of transduction technologies for teleoperator tactile sensing are known including resistive/conductive, semiconductor, piezoelectric capacitive and photoelectric. Hand-operated control means and manipulators of different types may be employed using a wide variety of well-known mechanisms and electromechanical elements including, for example, gimbals, linkages, pulleys, cables, drive belts and bands, gears, optical or electromagnetic position encoders, and angular and linear motors. Force feedback

to the operator requires use of body contact with hand-operated control means. Both hand grip type hand controllers such as those illustrated, and control brace type hand controllers are well adapted for use with the present invention for force feedback to the operator. Control brace hand controllers include use of structures with positive sensors mounted on the operator at joints for measuring joint angles. Force feedback then can be applied to each joint. Similarly, light fabric gloves with variable-resistance or fiber-optic flex sensors mounted on the joints for measuring bending of individual fingers may be used. Gloves of this type also may be provided with force feedback to provide for telepresence interaction with real objects. Regardless of the type of hand-operated control means employed, an image of the workspace is produced adjacent thereto to provide the operator with a sense that the end effector means and hand-operated control means are substantially integral. Also, as noted above, servomechanisms of many different types are well known in the robotic and teleoperator system arts, and the invention is not limited to any particular type. Those that include force and torque feedback to the operator are preferred to contribute to a telepresence sense of operation. In addition, many different means for producing a stereoscopic image of the workspace are known. For example, instead of using two cameras, a single camera may be employed together with switched cross-polarizing elements in the image receiving path. In this case, a pair of spaced stereoscopic lenses are used for viewing the workspace from different angles and providing first and second images thereof to the camera. In the Fig. 9 arrangement, wherein a laparoscope is shown, other types of endoscopes may be used for viewing the workspace. As noted above, the invention is not limited to any particular application or use. In the

- biomedical field, uses include, for example, open surgery, including surgery from a remote location, microsurgery, and minimum invasive surgery such as laparoscopic and endoscopic surgery. Laboratory use
- 5 including microscopic manipulation also is contemplated. Industrial use of the invention include, for example, hazardous materials handling, remote operations, microassembly, and the like. Military and undersea use of the teleoperator system of this system are apparent.
- 10 It is intended that the above and other such changes and modifications shall fall within the spirit and scope of the invention defined in the appended claims.

I CLAIM:

1. A teleoperator system for manipulating objects located in a workspace at a worksite by an operator from a remote control operator's station comprising,
 - 5 manipulator means at the work site including end effector means for manipulation of an object at the workspace,
 - controller means including hand-operated means at the control station connected to said manipulator means for remote control of the manipulator means by control of
 - 10 the hand-operated means by the operator,
 - video camera means for viewing the workspace, and means responsive to the video camera means for producing an image of the workspace which image is
 - 15 located adjacent the hand-operated means for viewing by the operator in the direction of said hand-operated means during operation of the hand-operated means and providing the operator with a sense that the end effector means and hand-operated means are substantially integral.
- 20 2. A teleoperator system as defined in Claim 1 wherein said video camera means comprises means for viewing the workspace from different angles for production of stereoscopic signal outputs,
 - said means for producing an image comprising means
 - 25 for producing a 3-dimensional image of the workspace in response to said stereoscopic signal outputs.
3. A teleoperator system as defined in Claim 2 wherein the angle between the optical axes of said means for viewing the workspace is substantially equal to the
- 30 operator's interocular viewing angle of the image.
4. A teleoperator system as defined in Claim 2 wherein said hand-operated means comprises a control arm mounted

for movement in any pivotal direction, the image of the end effector means and position of the movable control arm as sensed by the operator providing the operator with a sense that the end effective means comprises an extension of the control arm.

5. A teleoperator system as defined in Claim 4 wherein said manipulator includes an arm mounted for movement in any pivotal direction, angular movement of the control arm by the operator producing substantially the same angular movement of the manipulator arm.

6. A teleoperator system as defined in Claim 5 wherein the length of path from the eyes of the operator to the image of the workspace and length of control arm are related by a factor k to the optical path length from the video camera means to the workspace and length of manipulator arm, respectively, where k is a constant.

7. A teleoperator system as defined in Claim 2 wherein said image viewable by the operator comprises a virtual image.

8. A teleoperator system as defined in Claim 7 wherein said means for producing an image includes display means for producing a top-to-bottom reversed 3-dimensional, real image of the workspace,

a mirror positioned in front of the operator so as to receive the reversed real image from the display means and to reflect the same toward the operator's eyes for viewing of said virtual image in the mirror.

9. A teleoperator system as defined in Claim 8 wherein the display means is located above the mirror and faces toward the mirror.

10. A teleoperator system as defined in Claim 7 wherein the display means faces downwardly at an angle from vertical.

11. A teleoperator system as defined in Claim 1 wherein
5 said manipulator means comprises first and second manipulators and said controller means comprises first and second hand-operated means for remote control of said first and second manipulators, respectively.

12. A teleoperator system as defined in Claim 1
10 including an endoscope comprising an operating section and an insertion section insertable in a cavity in which the workspace is located and having observing window means through which the workspace is viewed by the video camera means.

13. A teleoperator system as defined in Claim 12 wherein
15 said manipulator means includes an operating section and insertion section insertable in said cavity for manipulation of an object in the cavity.

14. A teleoperator system as defined in Claim 13
20 wherein said manipulator means comprise first and second manipulators and said controller means comprise first and second hand-operated means for remote control of said first and second manipulators, respectively.

15. A teleoperator system as defined in Claim 14
25 including means for attaching the operating sections of the manipulators and endoscope to a support rail of a surgical table for support thereof during surgery.

16. A teleoperator system as defined in Claim 1 including force feedback from the manipulator means to

the hand-operated means which, together with said image of the workspace, provides for visual and force telepresence operation of the system.

17. A teleoperator system as defined in Claim 1 including first and second stereophonic microphones for picking up sounds from the workspace, and first and second speakers at the remote control station responsive to outputs from said respective first and second microphones for producing a stereophonic sound output and providing the operator with an audio perspective present at the workspace.

18. A teleoperator system as defined in Claim 1 wherein said means for producing an image of the workspace includes display means for producing a real image of the workspace adjacent the hand operated means for direct viewing by the operator.

19. A teleoperator system as defined in Claim 1 including an endoscope having an accessory channel, and wherein said manipulator means comprising a steerable catheter extending through the channel, said end effector means being carried by said steerable catheter, said workspace being viewed by said video camera means through said endoscope.

20. In a method of performing surgery by an operator at a remote location which includes, inserting the insertion end of an endoscope and of first and second manipulators into a subject, supporting the operating ends of the endoscope and first and second manipulators, employing said endoscope for viewing an object

inside the subject by video camera means,

controlling said first and second manipulators by
respective first and second hand-operated controllers
remotely located from said manipulators, and

5 presenting an image of the object viewed by the
video camera means at a location adjacent the first and
second hand-operated controllers for viewing by the
operator during operation of the first and second hand-
operated controllers and providing the operator with a
10 sense that the first and second manipulators, and
respective first and second hand-operated controllers are
substantially integral.

21. In a method as defined in Claim 20 wherein a
stereoscopic video camera is employed for viewing the
15 object by said endoscope, and

wherein the image presented is a 3-dimensional
image.

22. In a method as defined in Claim 20 which includes
presenting a magnified image of the object for viewing by
20 the operator.

23. In a method as defined in Claim 20 wherein the image
viewed by the operator comprises a virtual image.

24. In a method as defined in Claim 23 wherein the image
viewed by the operator comprises a real image.

25 25. In a method as defined in Claim 20 wherein the
endoscope and first and second manipulators are inserted
into the subject's abdomen, said method including
insufflating the abdomen.

AMENDED CLAIMS

[received by the International Bureau on 8 June 1993 (08.06.93);
original claims 1-8,10,11,13-21,24 and 25 amended;
new claims 26-32 added; other claims unchanged (7 pages)]

1. A teleoperator system for manipulating objects located in a workspace at a worksite by an operator from an operator's control station located remotely from the worksite comprising,

5 manipulator means at the worksite including a first movable manipulator arm and first end effector means at one end of said first manipulator arm for manipulation of an object at the workspace,

10 controller means including first hand-operated movable control means at the operator's control station connected by servomechanism means to said manipulator means for remote control of said first movable manipulator arm by control of said first hand-operated movable control means by the operator, said controller means including stationary support means at the operator's control station for supporting said first hand-operated movable control means,

20 video camera means for viewing the workspace, and means responsive to the video camera means for producing an image of the workspace which said workspace image is located adjacent said first hand-operated movable control means for viewing by the operator in the direction of said first hand-operated movable control means during operation of said first hand-operated movable control means, proprioceptive awareness by the operator of the operator's hand position in combination with said workspace image providing the operator with a sense that the first end effector means and first hand-operated movable control means are substantially integral, said video camera means being located relative to said first movable manipulator arm such that the direction of movement of said one end of said first movable manipulator arm relative to said video camera means in response to operation of said first hand-operated movable control means is substantially the same as the direction of movement of said first hand-operated movable control means relative to the operator's eyes.

2. A teleoperator system as defined in Claim 1 wherein said video camera means comprises means for generating stereoscopic signal outputs,

5 said image producing means comprising means for producing a 3-dimensional image of the workspace in response to said stereoscopic signal outputs.

10 3. A teleoperator system as defined in Claim 2 wherein said video camera means comprises means for viewing the workspace from different angles such that the angle between the optical axes of said workspace viewing means is substantially equal to the operator's interocular viewing angle of the image.

15 4. A teleoperator system as defined in Claim 1 wherein said first hand-operated movable control means comprises a first hand-operated movable control arm, which first hand-operated movable control arm and first movable manipulator arm are mounted for movement in any pivotal direction, the image of the first end effector means and position of the first movable control arm as sensed by
20 the operator providing the operator with a sense that the first end effector means comprises an extension of said first hand-operated movable control arm.

25 5. A teleoperator system as defined in Claim 4 wherein angular movement of said first hand-operated movable control arm by the operator produces substantially the same angular movement of said first movable manipulator arm.

30 6. A teleoperator system as defined in Claim 5 wherein path length from eyes of the operator to said workspace image and length of said first hand-operated movable control arm are related by a scale factor k to the optical path length from the video camera means to the workspace and length of said first movable manipulator arm, respectively, where scale factor k corresponds to

magnification of said workspace image.

7. A teleoperator system as defined in Claim 1 wherein said workspace image viewable by the operator comprises a virtual image.

5 8. A teleoperator system as defined in Claim 7 wherein said means for producing an image includes display means for producing a top-to-bottom reversed 3-dimensional, real image of the workspace,

10 a mirror positioned in front of the operator so as to receive the reversed real image from the display means and to reflect the reversed real image toward the operator's eyes for viewing of said virtual image in the mirror.

15 9. A teleoperator system as defined in Claim 8 wherein the display means is located above the mirror and faces toward the mirror.

10. A teleoperator system as defined in Claim 8 wherein the display means faces downwardly at an angle from vertical.

20 11. A teleoperator system as defined in Claim 1 wherein said manipulator means further comprises a second manipulator arm and second end effector means at one end of said second manipulator arm and said controller means further comprises a second hand-operated movable control
25 means for remote control of said second manipulator arm.

30 12. A teleoperator system as defined in Claim 1 including an endoscope comprising an operating section and an insertion section insertable in a cavity in which the workspace is located and having observing window means through which the workspace is viewed by the video camera means.

13. A teleoperator system as defined in Claim 12 wherein at least a portion of said first manipulator arm is insertable in said cavity for manipulation of an object in the cavity.

5 14. A teleoperator system as defined in Claim 13 wherein said manipulator means further comprises a second movable manipulator arm and second end effector means at one end of said second manipulator arm and said controller means further comprises second hand-operated movable control
10 means for remote control of said second manipulator arm, at least a portion of said second movable manipulator arm being insertable into said cavity for manipulation of an object in the cavity.

15 15. A teleoperator system as defined in Claim 14 including means for attaching said first and second manipulator arms and said endoscope to a surgical table for support thereof during surgery.

20 16. A teleoperator system as defined in Claim 1 including force feedback from said manipulator means to said first hand-operated movable control means which provides for force telepresence operation of the system.

25 17. A teleoperator system as defined in Claim 1 including first and second stereophonic microphones for picking up sounds from said workspace, and first and second speakers at the remote control station responsive to outputs from said first and second microphones, respectively, for producing a stereophonic sound output and providing the operator with an audio perspective present at the workspace.

30 18. A teleoperator system as defined in Claim 1 wherein said means for producing an image of the workspace includes display means for producing a real image of the

workspace adjacent the first hand-operated movable control means for direct viewing by the operator.

19. A teleoperator system as defined in Claim 1 including an endoscope having at least one accessory channel, and wherein

said manipulator means further comprises at least one steerable catheter extending through said accessory channel, said end effector means being carried by said steerable catheter, said workspace being viewable by said video camera means through said endoscope.

20. In a method of performing surgery by an operator at a remote location which includes,

inserting the insertion end of first and second manipulators comprising first and second movable arms with first and second end effectors, respectively, into a subject,

inserting the insertion end of an endoscope into the subject,

supporting the operating end of the endoscope and said first and second manipulators,

employing said endoscope for viewing an object inside the subject by video camera means,

controlling said first and second movable arms of said manipulators by respective first and second hand-operated control arms of controllers remotely located from said first and second manipulators,

controlling said first and second end effectors by respective first and second means at said first and second control arms, respectively, and

presenting an image of the object viewed by the video camera means at a location adjacent the first and second hand-operated control arms for viewing by the operator during operation of the first and second hand-operated control arms and for providing the operator with a sense that the first and second end effectors and respective first and second hand-operated control arms

are substantially integral.

21. In a method as defined in Claim 20 which includes employing a stereoscopic video camera for viewing the object by said endoscope, and

5 wherein the image presented is a 3-dimensional image.

22. In a method as defined in Claim 20 which includes presenting a magnified image of the object for viewing by the operator.

10 23. In a method as defined in Claim 20 wherein the image viewed by the operator comprises a virtual image.

24. In a method as defined in Claim 20 wherein the image viewed by the operator comprises a real image.

15 25. In a method as defined in Claim 20 wherein the endoscope and said first and second manipulators are inserted into the subject's abdomen, including the step of insufflating the subject's abdomen.

20 26. A teleoperator system as defined in Claim 1 wherein said controller means includes means at said first hand-operated movable control means connected by servomechanism means to said first end effector means for remote operation of said first end effector means by operator control of said means at said first hand-operated movable control means.

25 27. A teleoperator system as defined in Claim 26 wherein said first hand-operated movable control means comprises a first hand-operated movable control arm to which said means for remote operation of said first end effector means is affixed.

30 28. A teleoperator system as defined in Claim 1 wherein

said workspace image comprises a magnified image of said workspace.

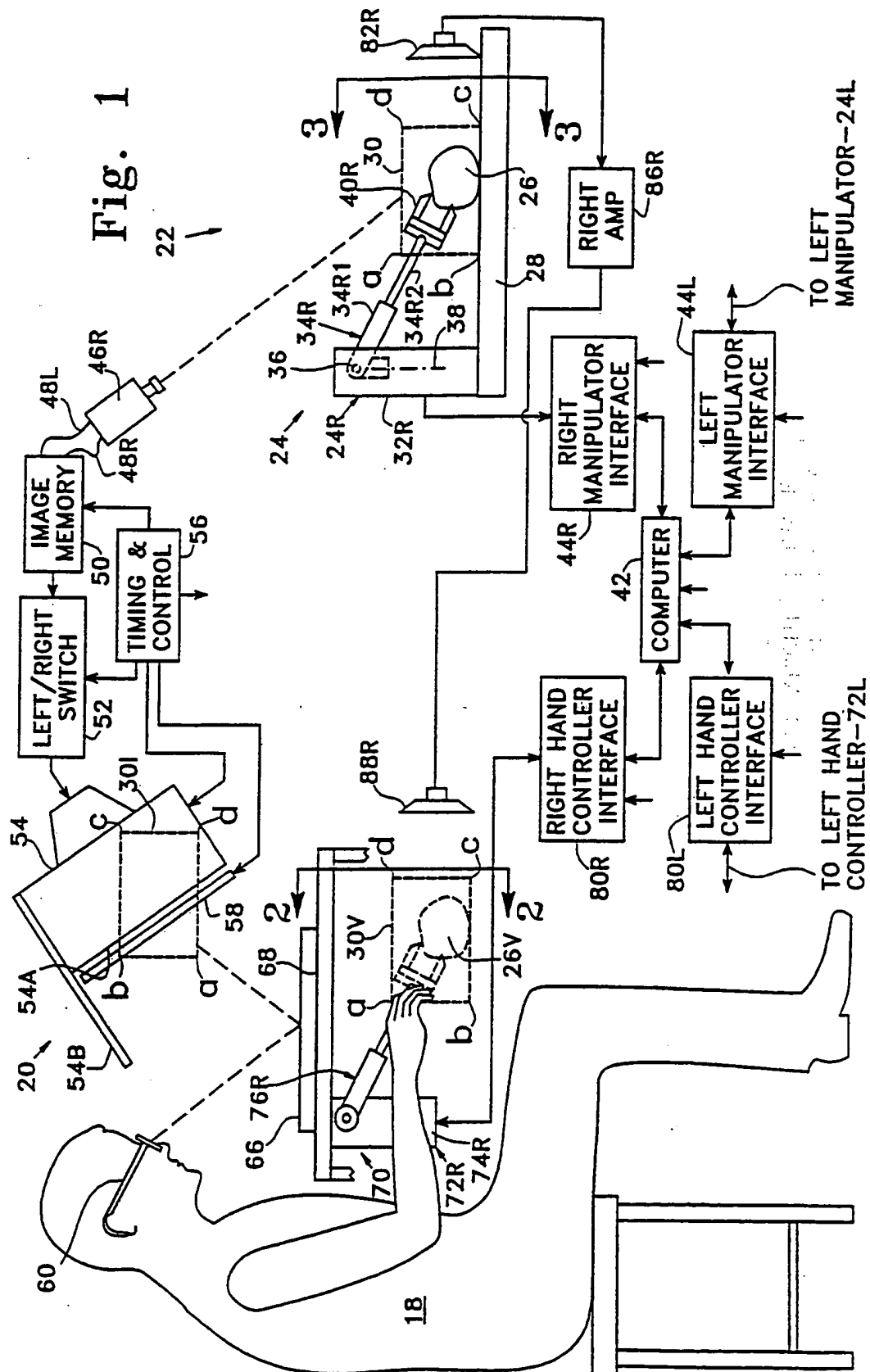
5 29. A teleoperator system as defined in Claim 28 wherein movement of said first hand-operated movable control means is related to resultant movement of said first movable manipulator arm by a scale factor corresponding to magnification of said workspace image.

10 30. A teleoperator system as defined in Claim 1 wherein said first movable manipulator arm and first hand-operated movable control means have the same degrees of freedom.

15 31. A teleoperator system as defined in Claim 1 including a microphone for picking up sounds from said workspace, and
a speaker at the operator's control station responsive to output from said microphone.

20 32. A teleoperator system as defined in Claim 8 wherein said display means comprises a monitor with a scan that is inverted relative to the workspace image from the video camera means.

Fig. 1



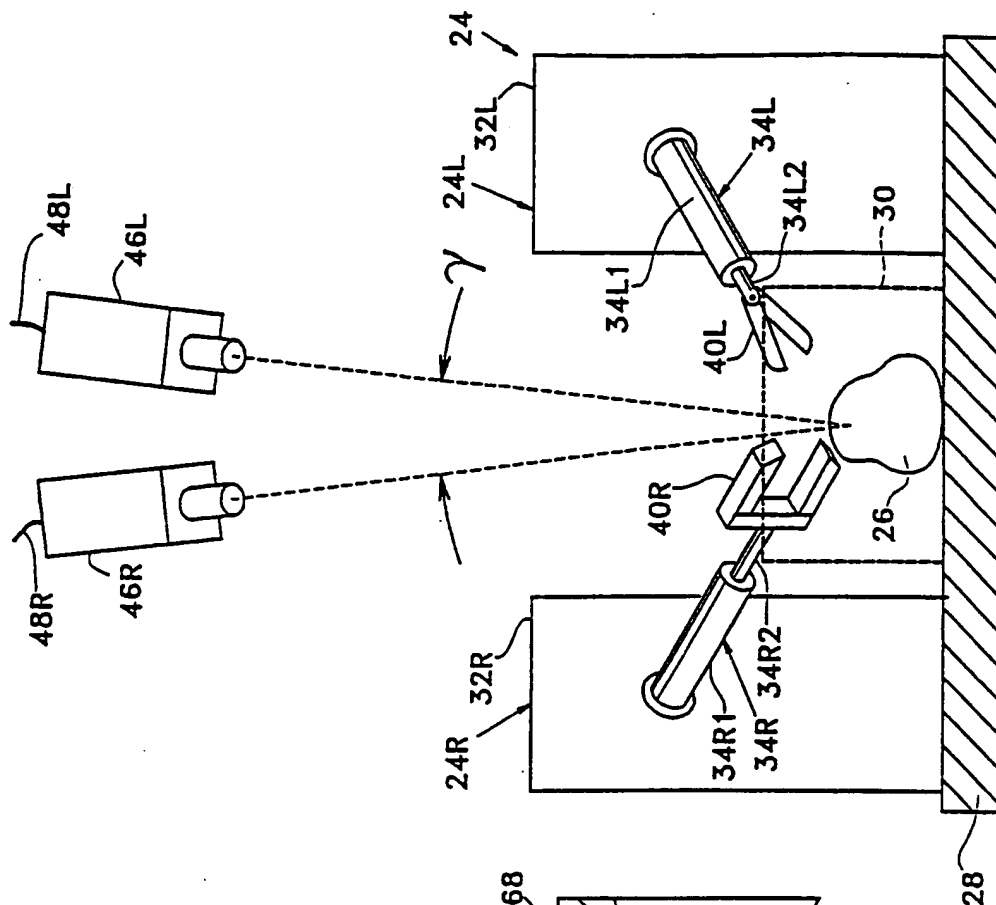


Fig. 3

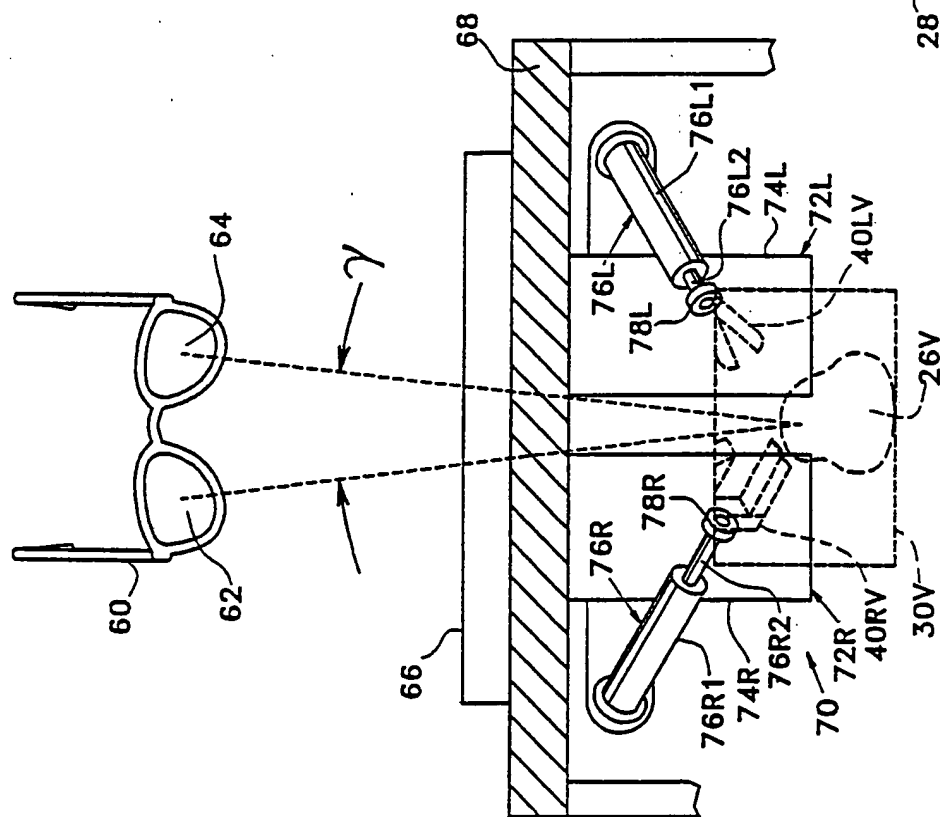
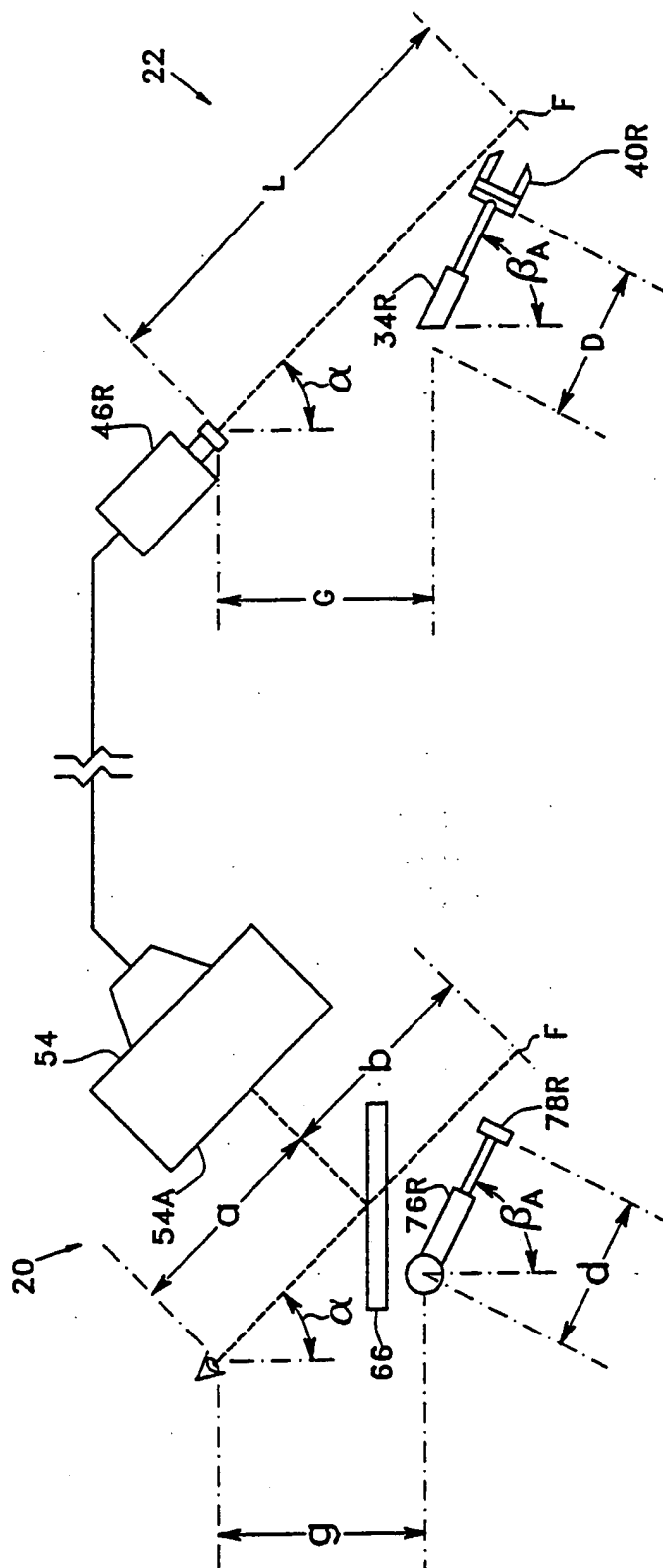


Fig. 2

Fig. 4



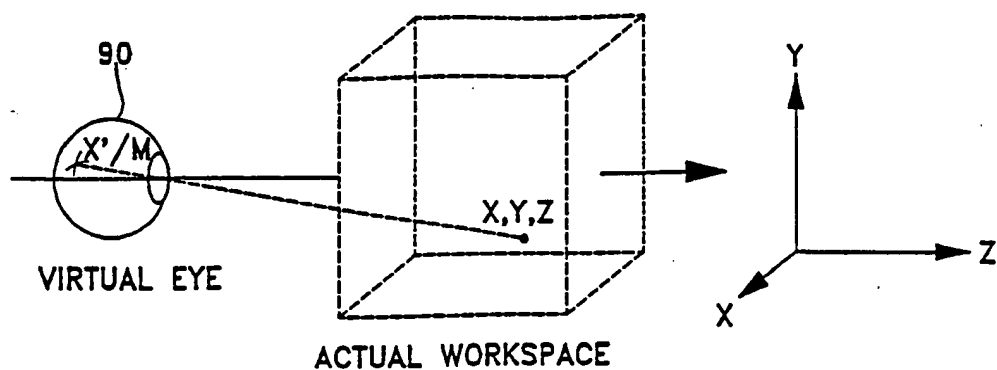


Fig. 5

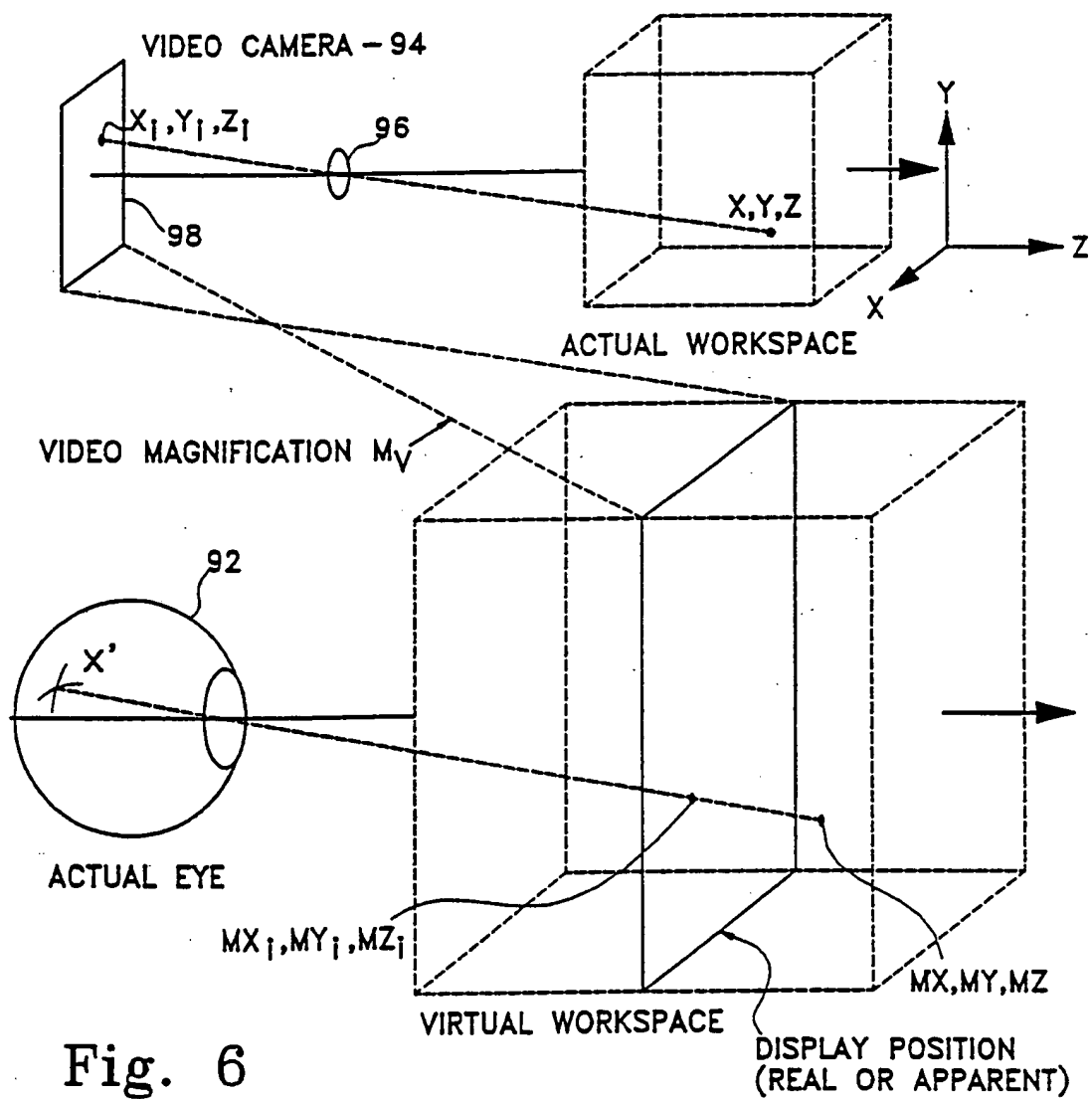


Fig. 6

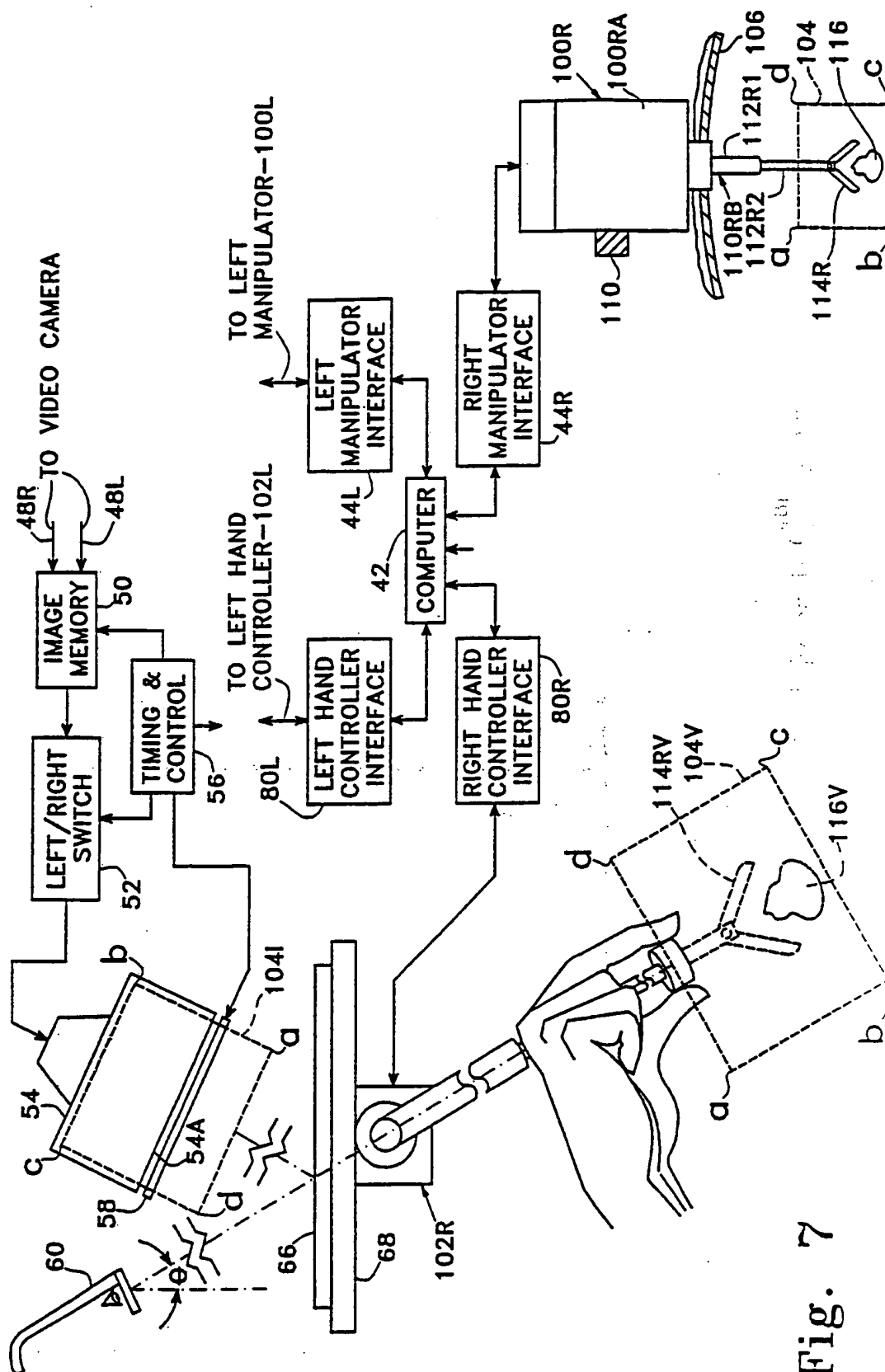


Fig. 7

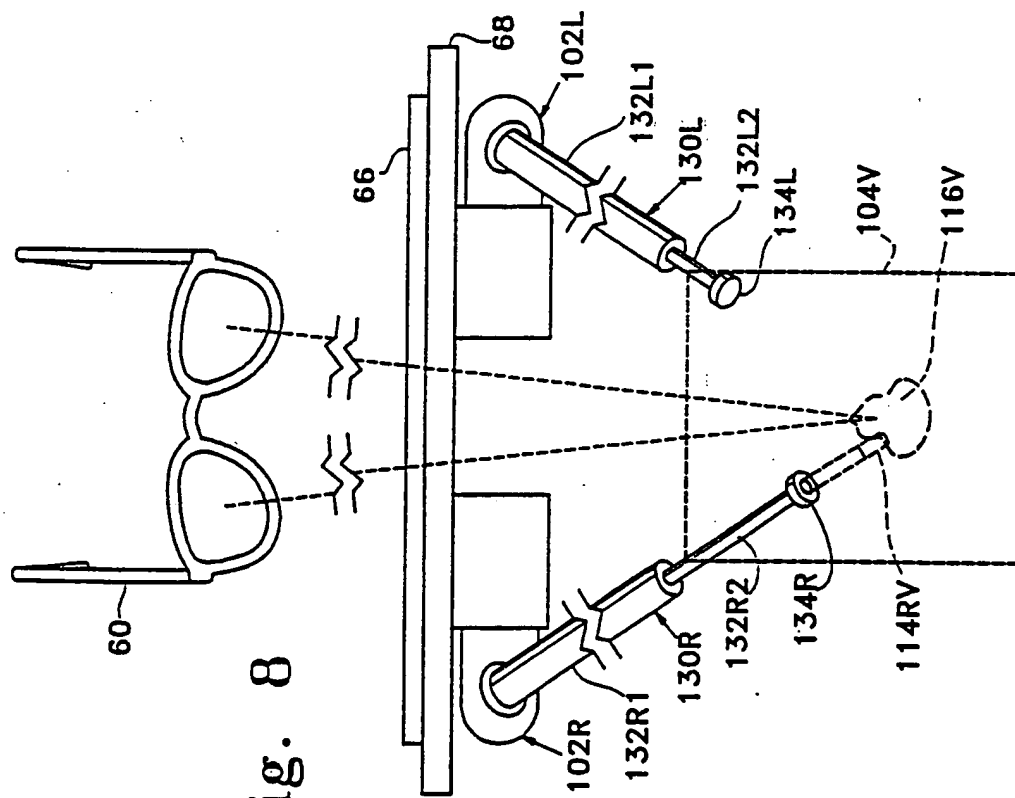


Fig. 8

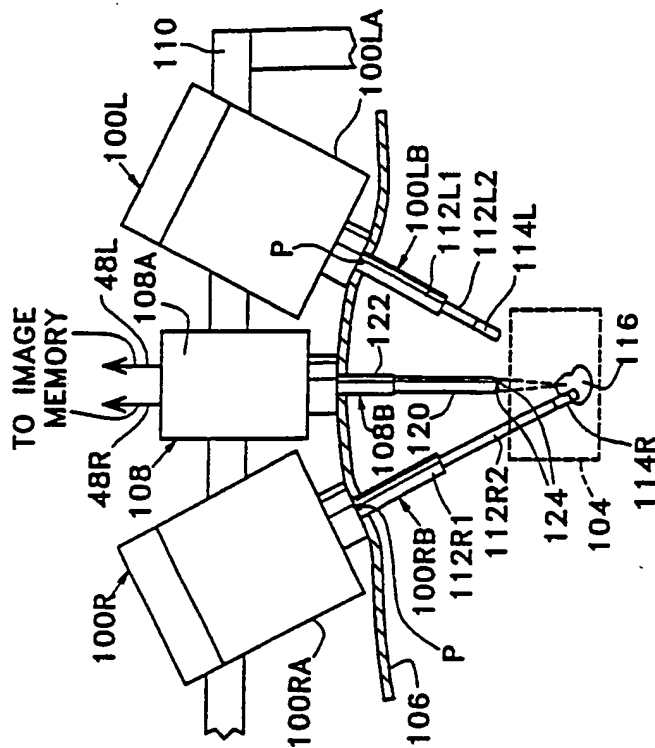
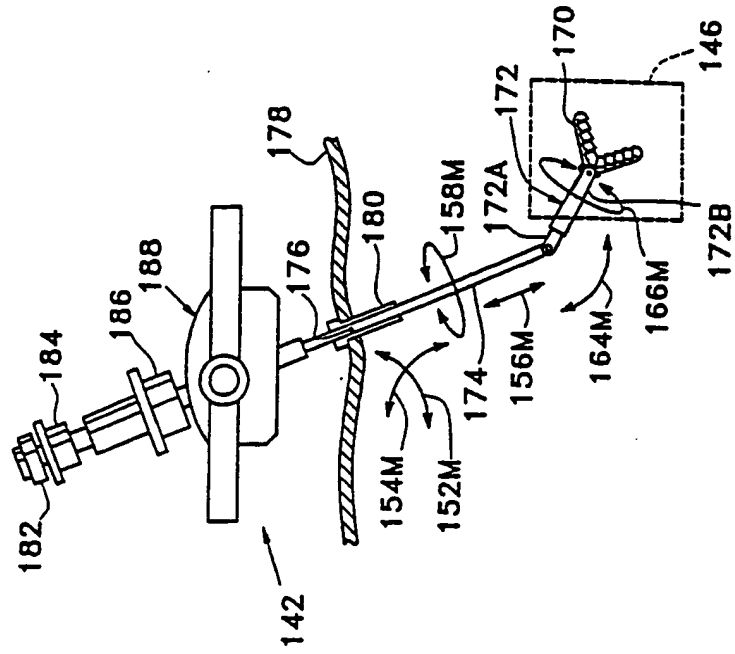
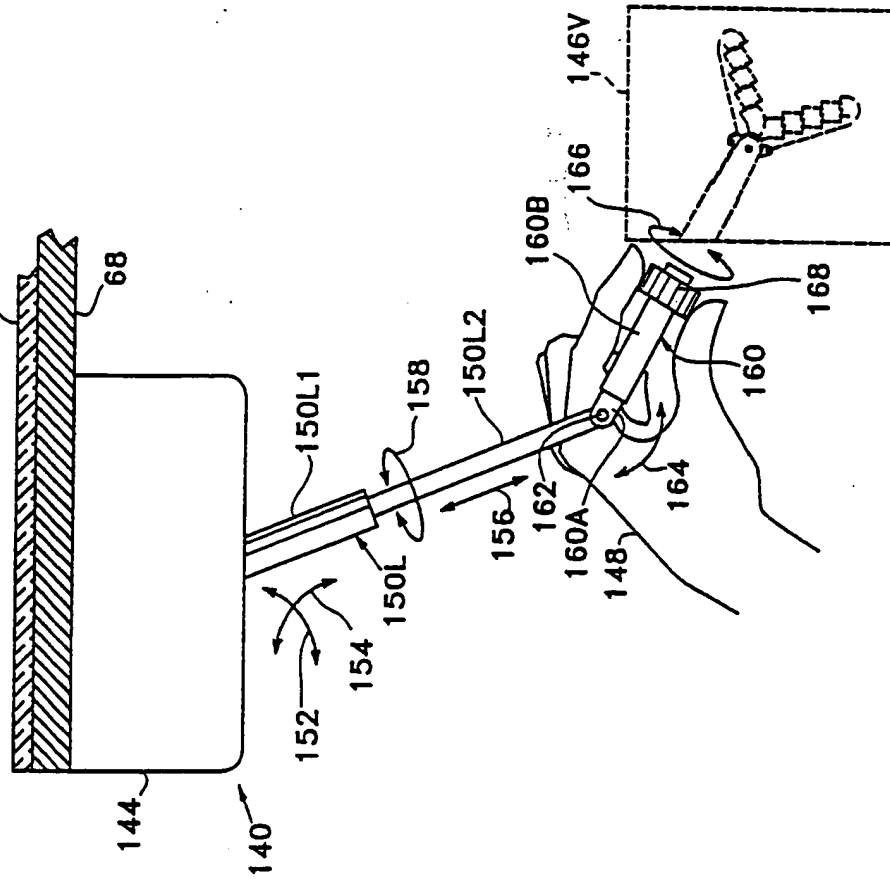
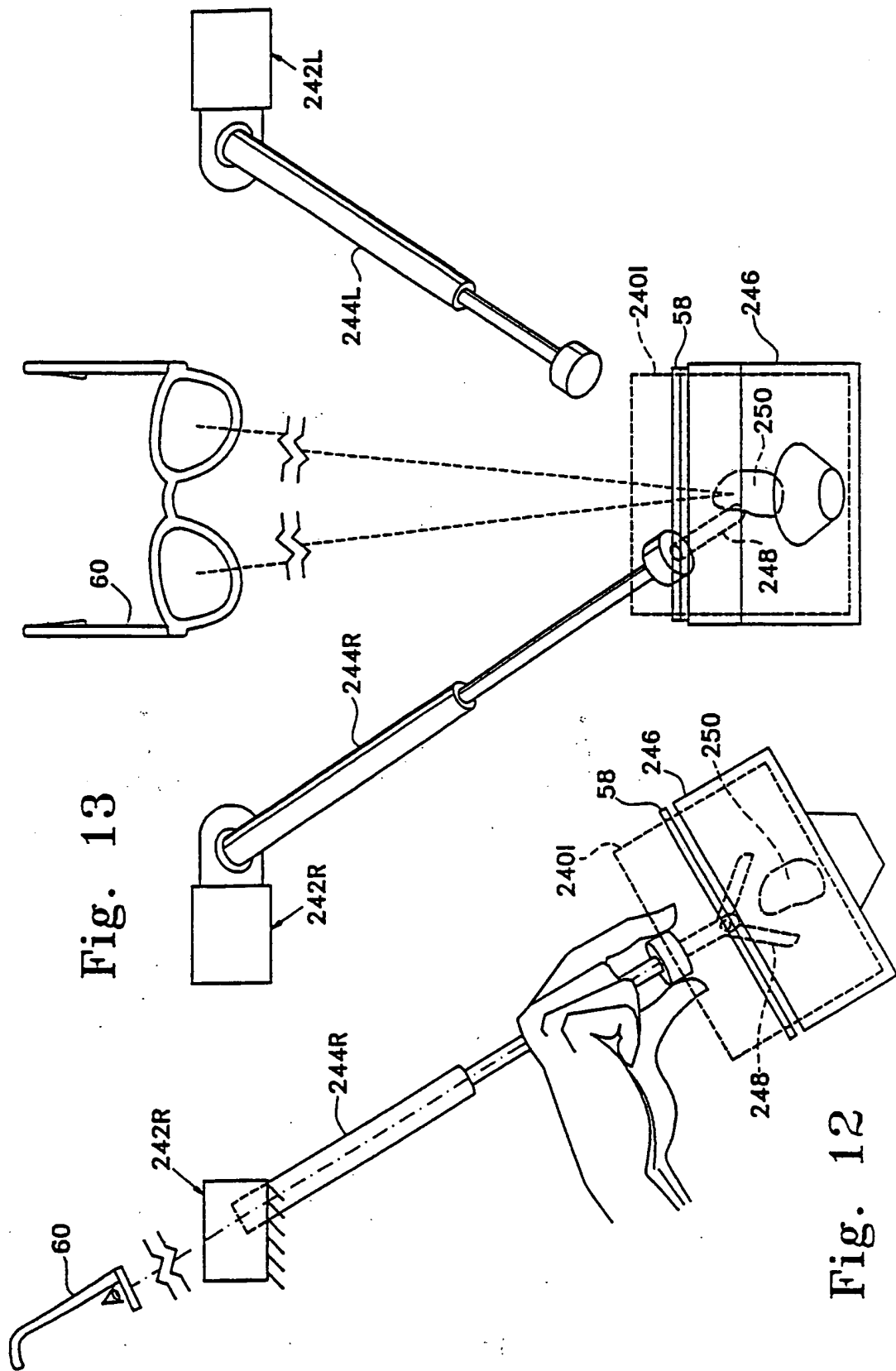


Fig. 9

Fig. 10

Fig. 11





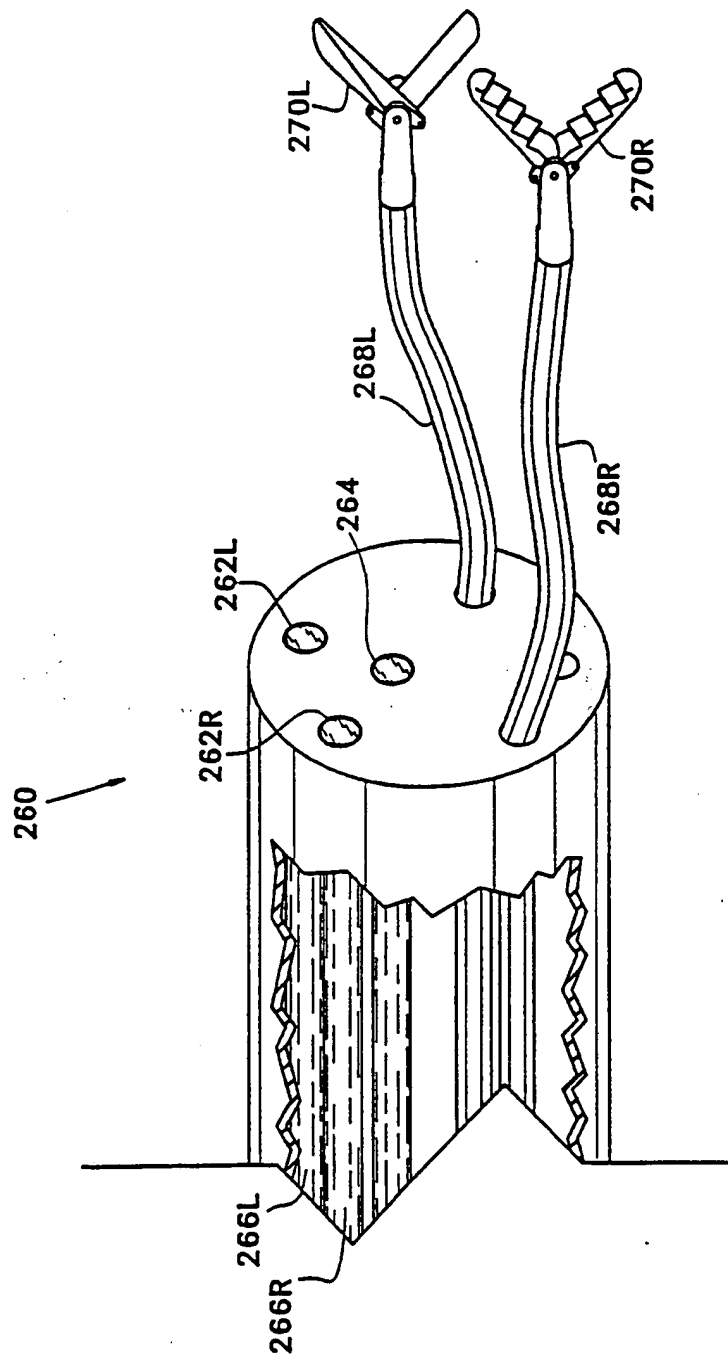


Fig. 14

INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 93/00309

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) ⁶ According to International Patent Classification (IPC) or to both National Classification and IPC Int.Cl. 5 B25J19/02; A61B1/04; B25J3/04														
II. FIELDS SEARCHED <div style="text-align: center; margin-top: 10px;">Minimum Documentation Searched⁷</div> <table border="1" style="width: 100%; border-collapse: collapse; margin-top: 5px;"> <tr> <td style="width: 30%; padding: 5px;">Classification System</td> <td style="padding: 5px;">Classification Symbols</td> </tr> <tr> <td style="padding: 5px;">Int.Cl. 5</td> <td style="padding: 5px;">B25J ; A61B ; G06F</td> </tr> </table> <div style="text-align: center; margin-top: 10px;">Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched⁸</div>			Classification System	Classification Symbols	Int.Cl. 5	B25J ; A61B ; G06F								
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Int.Cl. 5	B25J ; A61B ; G06F													
III. DOCUMENTS CONSIDERED TO BE RELEVANT⁹ <table border="1" style="width: 100%; border-collapse: collapse; margin-top: 5px;"> <tr> <th style="width: 10%; padding: 5px;">Category¹⁰</th> <th style="width: 70%; padding: 5px;">Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²</th> <th style="width: 20%; padding: 5px;">Relevant to Claim No.¹³</th> </tr> <tr> <td style="text-align: center; vertical-align: top; padding: 5px;">X</td> <td style="padding: 5px;"> PROCEEDINGS OF THE 29TH CONFERENCE ON DECISION AND CONTROL, HONOLULU, HAWAI. DECEMBER 1990. VOLUME 1 OF 6. PAGES 85-90 TACHI ET AL.: TELE-EXISTENCE MASTER SLAVE SYSTEM FOR REMOTE MANIPULATION see page 86, paragraph 2 - page 88 </td> <td style="text-align: center; vertical-align: top; padding: 5px;">1-5, 7, 16-18</td> </tr> <tr> <td style="text-align: center; vertical-align: top; padding: 5px;">Y A</td> <td style="padding: 5px;"> --- 33 IEEE COMPUTER SOCIETY INTERNATIONAL CONFERENCE, SAN FRANCISCO, CALIFORNIA, MARCH 1988. PAGES 543-547. KIM ET AL.: A HELMET MOUNTED DISPLAY FOR TELEROBOTICS see page 544, column 2 --- </td> <td style="text-align: center; vertical-align: top; padding: 5px;">11, 12, 19 8, 9, 21, 23, 24</td> </tr> <tr> <td style="text-align: center; vertical-align: top; padding: 5px;">Y</td> <td style="padding: 5px;"> --- 33 IEEE COMPUTER SOCIETY INTERNATIONAL CONFERENCE, SAN FRANCISCO, CALIFORNIA, MARCH 1988. PAGES 543-547. KIM ET AL.: A HELMET MOUNTED DISPLAY FOR TELEROBOTICS see page 544, column 2 --- </td> <td style="text-align: center; vertical-align: top; padding: 5px;">11</td> </tr> </table> <div style="text-align: right; margin-top: 10px;">-/-</div>			Category ¹⁰	Citation of Document, ¹¹ with indication, where appropriate, of the relevant passages ¹²	Relevant to Claim No. ¹³	X	PROCEEDINGS OF THE 29TH CONFERENCE ON DECISION AND CONTROL, HONOLULU, HAWAI. DECEMBER 1990. VOLUME 1 OF 6. PAGES 85-90 TACHI ET AL.: TELE-EXISTENCE MASTER SLAVE SYSTEM FOR REMOTE MANIPULATION see page 86, paragraph 2 - page 88	1-5, 7, 16-18	Y A	--- 33 IEEE COMPUTER SOCIETY INTERNATIONAL CONFERENCE, SAN FRANCISCO, CALIFORNIA, MARCH 1988. PAGES 543-547. KIM ET AL.: A HELMET MOUNTED DISPLAY FOR TELEROBOTICS see page 544, column 2 ---	11, 12, 19 8, 9, 21, 23, 24	Y	--- 33 IEEE COMPUTER SOCIETY INTERNATIONAL CONFERENCE, SAN FRANCISCO, CALIFORNIA, MARCH 1988. PAGES 543-547. KIM ET AL.: A HELMET MOUNTED DISPLAY FOR TELEROBOTICS see page 544, column 2 ---	11
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Y A	--- 33 IEEE COMPUTER SOCIETY INTERNATIONAL CONFERENCE, SAN FRANCISCO, CALIFORNIA, MARCH 1988. PAGES 543-547. KIM ET AL.: A HELMET MOUNTED DISPLAY FOR TELEROBOTICS see page 544, column 2 ---	11, 12, 19 8, 9, 21, 23, 24												
Y	--- 33 IEEE COMPUTER SOCIETY INTERNATIONAL CONFERENCE, SAN FRANCISCO, CALIFORNIA, MARCH 1988. PAGES 543-547. KIM ET AL.: A HELMET MOUNTED DISPLAY FOR TELEROBOTICS see page 544, column 2 ---	11												
<div style="display: flex; justify-content: space-between;"> <div style="width: 45%;"> <p>¹⁰ Special categories of cited documents:</p> <p>"A" document defining the general state of the art which is not considered to be of particular relevance</p> <p>"E" earlier document but published on or after the international filing date</p> <p>"I" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)</p> <p>"O" document referring to an oral disclosure, use, exhibition or other means</p> <p>"P" document published prior to the international filing date but later than the priority date claimed</p> </div> <div style="width: 45%;"> <p>"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention</p> <p>"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step</p> <p>"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.</p> <p>"A" document member of the same patent family</p> </div> </div>														
IV. CERTIFICATION <table border="1" style="width: 100%; border-collapse: collapse; margin-top: 5px;"> <tr> <td style="width: 50%; padding: 5px;"> Date of the Actual Completion of the International Search <div style="text-align: center; margin-top: 10px;">15 APRIL 1993</div> </td> <td style="width: 50%; padding: 5px;"> Date of Mailing of this International Search Report <div style="text-align: center; margin-top: 10px;">14. 05. 93</div> </td> </tr> <tr> <td style="padding: 5px;"> International Searching Authority <div style="text-align: center; margin-top: 10px;">EUROPEAN PATENT OFFICE</div> </td> <td style="padding: 5px;"> Signature of Authorized Officer <div style="text-align: center; margin-top: 10px;">LAMMINEUR P.C.G.</div> </td> </tr> </table>			Date of the Actual Completion of the International Search <div style="text-align: center; margin-top: 10px;">15 APRIL 1993</div>	Date of Mailing of this International Search Report <div style="text-align: center; margin-top: 10px;">14. 05. 93</div>	International Searching Authority <div style="text-align: center; margin-top: 10px;">EUROPEAN PATENT OFFICE</div>	Signature of Authorized Officer <div style="text-align: center; margin-top: 10px;">LAMMINEUR P.C.G.</div>								
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III. DOCUMENTS CONSIDERED TO BE RELEVANT (CONTINUED FROM THE SECOND SHEET)		
Category *	Citation of Document, with indication, where appropriate, of the relevant passages	Relevant to Claims No.
Y	DE,A,3 806 190 (OLYMPUS OPTICAL CO.) 8 September 1988 see claims 1,7,8	12
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**ANNEX TO THE INTERNATIONAL SEARCH REPORT
ON INTERNATIONAL PATENT APPLICATION NO.**

US 9300309
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This annex lists the patent family members relating to the patent documents cited in the above-mentioned international search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

15/04/93

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